Predictive Control Strategies using Simulink

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Project Overview
Project Overview

- This is a predictive control where the future data (static) is processed ahead and appropriate decisions are made.

- The scope of this project is on Battery management and thermal management.

- This project is more at a concept phase.

- Resulted in a consistent and substantial improvement in fuel economy.
# Vehicle configuration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Category</td>
<td>Heavy Duty Truck – Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>Engine</td>
<td>Max Torque: 2200 Nm@1100 rpm Max Power: 330 kW@1800 rpm</td>
</tr>
<tr>
<td>Alternate Power Source</td>
<td>E-motor with high voltage Battery</td>
</tr>
<tr>
<td>Transmission</td>
<td>12 speed AMT</td>
</tr>
<tr>
<td>Tire Rolling Radius</td>
<td>0.49 m</td>
</tr>
<tr>
<td>E-motor/Generator</td>
<td>Permanent magnet</td>
</tr>
<tr>
<td>Battery</td>
<td>Li-ion</td>
</tr>
<tr>
<td>Cooling setup</td>
<td>Radiator and Chiller based</td>
</tr>
<tr>
<td>Simulation Environment</td>
<td>Model-in-Loop Simulation</td>
</tr>
</tbody>
</table>
Motivation and Problem Statement
Fuel saving opportunities in Heavy Duty Trucks (1/2)

2014 - Petroleum Fuel Consumption distribution by Transportation Mode

- Light-Duty Vehicle: 0%
- Freight Heavy and Medium Duty: 1%
- Air, Passenger & freight: 1%
- Pipeline Fuel: 1%
- Military Use: 1%
- Shipping, International: 2%
- Commercial Light Duty Trucks: 1%
- Rail, Freight: 2%
- Recreation Boats: 9%
- Bus Transportation: 1%
- Shipping, Domestic: 3%
- Lubricants: 1%
- Rail, Passenger: 1%

Medium and Heavy Duty Truck platforms offer potential for Fuel saving

(Source: http://www.eia.gov/oiaf/aeo)
Fuel saving opportunities in Heavy Duty Trucks (2/2)

Vehicle Park Distribution

- Heavy Duty Trucks: 43%
- Medium Duty Trucks: 57%

Miles Traveled

- Heavy Duty Trucks: 74%
- Medium Duty Trucks: 26%

Fuel Consumption

- Heavy Duty Trucks: 82%
- Medium Duty Trucks: 18%

Fuel Economy improvement strategies have high significance in HDT

17% MDT + HDT
Problem statement

- Hybrid electric vehicles (HEV) are always expensive than conventional vehicle due to the 2 major components Battery and E-motor.
- This is compensated in the long run by the good fuel economy (FE) of HEV.
- But due to the inclusion of Intelligent Powertrain the gap in the fuel economy has reduced.
- Hence now it’s a challenge for HEV to come up with fuel economy improvement strategies.
Approach to the Problem (1/2)

- In HEV a control strategy has a flexibility to have a wide range of to torque splits between an Engine and E-motor as long as the driver demand is met.

- Hence to get a better FE over the current HEV, we can have control strategies, where we can play around the Engine+E-motor torque splits for most efficient usage of both the components.

- But instantaneously taking a decision on the torque split could have negative impact at a later point (like lack of State Of Charge (SOC) or saturation of SOC etc.).
• Hence having a predictive strategies where even the impact at future instances is foreseen and decisions are made.

• Predictions can be done based on the future road gradient mainly (in highway SOC, Driver demand etc. depends on the road gradient)
Predictive Thermal Management
Predictive Thermal Management (1/2)

Methodology

- The thermal management discussed here are regarding the Hybrid components such as Battery, Inverter and E-Motor.

- The temperature changes in these components are directly depended on the charge/discharge rate (change in SOC). SOC in turn is directly depended on the Road gradient in a Highway.

- Hence by collecting the future SOC (via Road gradient), the temperature changes in these components can be predicted.
How is FE improved?

• In an On/Off control strategy, due to the slow response of temperature the cooling pump will be triggered well before the critical temperature (Tc-X) is reached.

• But many of the times, after that point (Tc-X) the temperature may not have increased at all (due less/no Hybrid action).

• At such instances the cooling given is of no significance and can be avoided. Hence by predicting the future, optimum amount of cooling can be given.
To gather future data

Future SOC data in the form of array (.mat file)

Size of time window
For e.g. if Window = 120s
Then 120s of future SOC data will be considered

As for-iteration would be an exhaustive calculation, to optimize we use Enable.
E.g. once 120s of SOC data is gathered and a decision is taken based on that 120s, for the next 120s, no need for the calculation to take place, hence can be enabled every 120s

Note: Here SOC is derived from Road gradient
How Matlab-Simulink was utilized (2/3)

To calculate the predicted temperature

This directly related to the change in temperature

Initial temperature conditions of parameters that affect the component temperature

Note: Same logic is done for all the 3 Hybrid components
How Matlab-Simulink was utilized (3/3)

To calculate the optimum cooling

Predicted temperature (i.e. expected temperature after 120s)

Optimum cooling pump request for next 120s (based on how close the predicted temperature is to the critical temperature)

At this instant @ A the block gives the optimum amount of cooling for next 120s which would maintain the temperature below critical temperature

Note: Here 120s can be translated to distance based window
Results

At 0th second, based on the inputs the block predicts that the temperature will be 32°C at the end of 120s. The same is true for 10s calculations.

For European Highway

Note: Here 120s and 10s predictions were done to avoid sudden overshoots.
Predictive Battery Management
Predictive Battery Management (1/2)

Methodology

- The Battery management discussed here is regarding the State of Charge (SOC) of the high voltage Battery of HEV’s.

- Fuel consumption is least when entire driver demand is met by E-motor (low torque region) and Engine is switched off - E-motor Drive (EMD) mode.

- Hence by collecting the future SOC and Driver demand (via Road gradient), we can use SOC such a way that we make sure SOC is available at EMD modes.

Note: Here the vehicle should be in Highway (cruise mode)
Predictive Battery Management (2/2)

How is FE improved?

- In the default control strategy when SOC is available the E-motor is always gives maximum and remaining is given by Engine to meet the Driver demand.

- But many of the times there are situation where Driver demand would be very less (low torque region) but due to no availability of SOC Engine would be providing that and low torque regions have very bad BSFC values.

- Hence by saving appropriate amount of SOC for that low torque region, good FE can be achieved.

Hence drain SOC till X% only and use the X% at low torque region

Analyze the route and find Low torque region (requires X% SOC)
How Matlab-Simulink was utilized (1/2)

To gather future data

- Future SOC and Driver demand data in the form of array (.mat file)
- Size of the distance till which the route is analyzed
  - For e.g. if Look up distance = 4km
  - Then 4km of future SOC and Driver demand data will be analyzed

**Note**: Here SOC and Driver demand is derived from Road gradient
To calculate the optimum torque split

Amount of SOC required for the low torque region

Optimum torque split which would consume SOC only till X% after which Engine alone would be supporting till the starting point of low torque region, after which E-motor will take over completely.

Note: Here 4km can be changed to other values for better results.
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Dem_Trq
Max_Mtr_Trq
Eng_Trq_PBM
Eng_Trq_Old
Mtr_Trq_PBM
Mtr_Trq_Old
SOC_PBM
SOC_Old

Low Torque region

Engine Providing whole demand
Engine Torque at 0Nm
Motor Torque at 0Nm
Motor Providing whole demand

X%_SOC
Flag

SOC being reserved
SOC being Consumed

Results (1/2)
Results (2/2)

Additional Benefits

- No Change in vehicle dynamics and hence drivability is not affected (Same Average velocity)
- Battery bounds are unchanged
- No additional hardware required
Thank you